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# LiDAR Performance Review in Arctic Conditions

*Abstract*—**This article aims to outline the key results of testing and encountered challenges of various LiDARs, radar and stereo camera in arctic weather conditions. The test session was conducted in two different urban areas in Finland in the middle of January 2019. The arctic conditions turned out to be challenging for the sensors dedicated more to areas where temperature stays relatively warm. The aim of this one-week test session was to assess performance deterioration when powdered snow, salted road, snowy ground and sun light influence reliability of the future automated driving functions. This study focuses mainly on the issues with hardware that are basic building blocks for the situation awareness software modules. Furthermore, the countermeasures such as protecting sensors and mounting positions have been proposed.**

**The test results indicate that some sensors significantly lose performance when temperature drops to less than -10 degrees centigrade. The problem is not merely mechanical freezing of the spinning LiDAR components but properties of laser illumination may change due to temperature variation, too. Since LiDAR is an optical device, they also suffer when there is turbulent snow in front of the sensor. The turbulence looks like a noise and partially blocks the laser echoes from surrounding environment. The performance, measured by laser pulse echo count, can with some sensors drop more than 50 percent. This seriously diminishes the sensing range and furthermore, makes pattern recognition unreliable. The two other sensor types which were taken into account are stereo vision and radar. They have a role in automated driving to compensate performance degradation of LiDARs due to arctic conditions.**

***Keywords—automated driving; LiDAR; winter; laser; urban***

## I. INTRODUCTION

Automated driving is the mega-trend which is expected to change mobility habits of people within next 20 years time frame completely. Instead of buying new passenger car every now and then, people are expected to share their cars or use robo-taxies, especially in dense populated cities. However, the world is not ready for 24/7 autonomous cars today. There are manually driven cars which do not follow the traffic regulations 100%. This is of course, a non-technical restriction but even though the technology has taken significant steps forward, we are always limited by laws of physics. Automation has been part of indoor industrial automation for years. The vehicles operate outdoors where one cannot limit

1) *amount of sunlight*
2) *density of fog*
3) *physical properties of snow (wet, dry, slushy)*
4) *thickness of spraying water from front vehicle*
5) *density of salt in the road ahead*

This study is dedicated to analyze influence of these factors to sensing range and reliability of automated driving sensors. The well known fact is that e.g. LiDAR resolution drops in spraying water if switched to one echo mode for mitigating range resolution drop [1]. The test sessions have been conducted for various type of sensor devices especially optical ones which due to high resolution are envisioned to be the key automated driving sensors in the future [2].

The car sensors are typically installed either on the roof or on the bumper of the vehicle (see Fig. 1). This study aims to review how the sensor location influences their sensing range in various weather conditions. Sensors on the roof are better protected from the dirt but on the other hand, vehicle's immediate surroundings are not visible.

Existing studies have been conducted to mitigate influence of adverse weather for software dedicated to automated driving [3]. The aim is to optimize the sensor and data fusion parameters which take into account noise and limited range due to environmental weather conditions. The spectral response of the illumination depends on the wavelength and media in atmosphere [4]. The longer wavelengths >1400 nm penetrate better in the foggy conditions depending on the amount of liquid and the water droplet size. The exhaustive and repeatable verification of automotive LiDAR sensors have been done in [5].

## II. SENSORS USED

Selected sensors for the tests were LiDARs from four different manufacturers, one radar (Continental SRR2-A) and

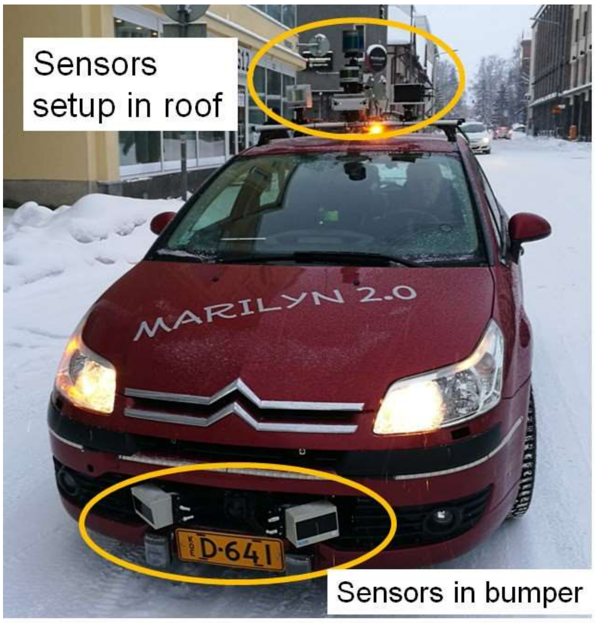


Fig. 1. Trial vehicle used in the field tests.

TABLE I. SPECIFICATIONS OF THE SENSORS USED IN THE TESTS

| | Cepton HR80T | Ibeo Lux (Sick LD-MRS) | Velodyne Puck VLP-16 | Robosense RS-LiDAR-32 | Visblab 3DV-E 29 (stereo camera) | Continental SRR2-A (radar) |
|---|---|---|---|---|---|---|
| **Sensor type** | Flash LiDAR, 80 x 80 pix | Spinning, 4 layers | Spinning, 16 layers | Spinning, 32 layers | Stereo camera, 636x476 disparity map, 640x480 grayscale image | Radar, resolution 1 m, accuracy 0.2 m |
| **Wavelength** | 905 nm | 905 nm | 908 nm | 905 nm | Visible light | - |
| **Range** | 300 m | 50 m @ 10% | 100 m | 0.2 … 200 m @ 20% | 0.5 … 65 m | 1 … 50 m |
| **Operating temperature** | -20 … 65 °C | -40 … 85 °C | -10 … 60 °C | -10 … 60 °C | 0 … 40 °C | -40 … 85 °C |

one stereo camera (Vislab 3DV-E 29). The LiDARs included Cepton HR80T, Ibeo Lux (Sick LD-MRS), Velodyne Puck VLP-16 and Robosense RS-LiDAR-32. Ibeo, Velodyne and Robosense are scanning LiDARs with multiple superimposed layers to cover the surroundings both horizontally and vertically. Cepton, on the other hand, is a flash-based LiDAR, which also includes a scanning mechanical component for data acquisition. Sensor specifications are presented in more detail in TABLE I. Radar was installed behind the bumper and the other sensors on the roof (see Fig. 2).

## III. PERFORMED TESTS

Tests were performed in January 2019 in a small town in Eastern Finland driving in urban and semi-urban roads, and motorway. Wintery weather varied from sunny and dry to dark and cloudy days with light snowfall. Temperature values were between 0 to -10°C. The road surface conditions changed, too, from dry and clean to road being covered with slush, salty water, ice or turbulent snow.

Tests scenarios included the effects of temperature, turbulent snow, salted water and oncoming light on the sensor performance. For each of these scenarios a reference run was driven and measured where the road surface was clean and there was no snow/rainfall. The same route was driven repeatedly to measure all the interesting scenarios with the different weather and road conditions.

## IV. RESULTS

The results are calculated so that for each sensor region of interest was selected. The region covers one meter to the right and left from the sensor, and 10 meters in front of it. Echo count presented in the graphs' Y-axis is the total number of reflections received from this region. For echo count calculation, new C++ based script was developed based on optical distance measurement principles with LiDARs. Script calculates from sensor raw data, how many echoes one laser pulse generates inside sensor region of interest [6]. There is no distinction if the echo is the first, second or third, but all are considered equal. In general, high echo count reflects disturbances in the measurement. On the X-axis, test run's time span is shown. Values for the stereo camera's results are calculated differently. Instead of echo counts, the clarity of the view is estimated by calculating a blurriness index. The smaller the index the sharper the image is, i.e. there are more details in the image.

### A. Temperature

Influence of temperature to the performance of sensors was evaluated by gathering data in subzero temperatures (-1°C, -5°C and -10°C degrees). The echo count charts and their ranges do not seem to depend on the changes in temperatures. However, according to our experience the lower temperatures do influence the performance of certain sensors even though this effect is not visible in the echo count evaluation.

Cepton and Robosense begin to work poorly when the temperature drops below -5°C. Cepton starts to lose sectors and creates non-existing sample points (marking them as zeroes). According to their specifications provided by the manufacturers, they should still function in this temperature. Both Cepton's and Robosense's performance continue to deteriorate the lower the temperature fell. At -10°C, they both lose their capability to detect objects thus making their data unusable. In Robosense, the cold causes additional echo points

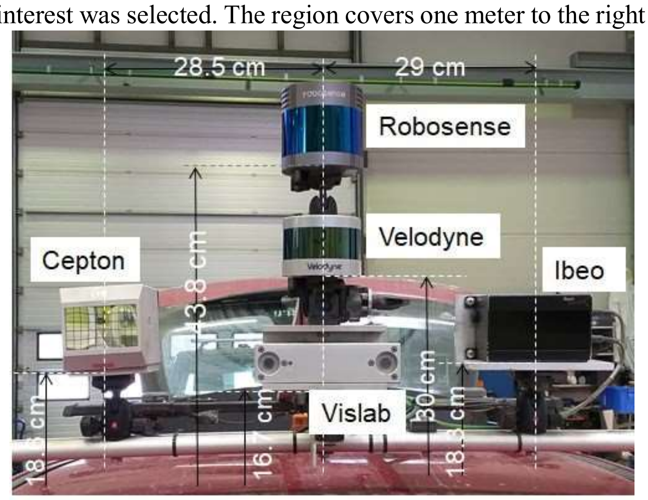


Fig. 2. Sensor installation on the roof of the trial car

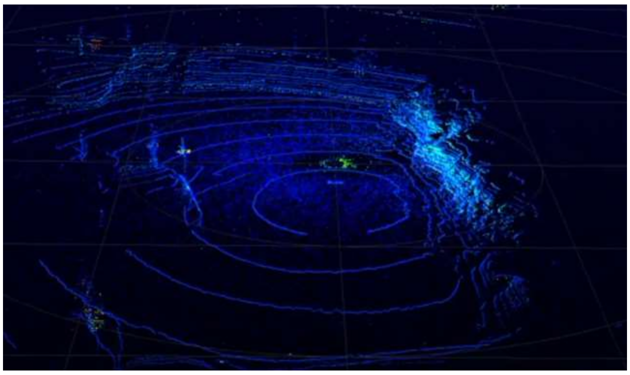

Fig. 3. Robosense's point cloud data, -10°C temperature.

surrounding the sensor thus making the environment monitoring impossible (Fig. 3).

Rest of the sensors are not this crucially affected by the cold temperatures and work as they should.

## B. *Salted water*

Salted water tests were driven in two different environments: at lower speeds in urban roads and at higher speeds in motorway. It is notable, that at lower speeds the spraying water from the road surface does not reach the sensors located on the roof of the vehicle. Thus, their performance does not deteriorate in this case. However, when the vehicles move faster the water rises higher creating a mist cloud, which blocks the sensors' view. It also dirties the sensors both on the bumper and on the roof.

As an example of LiDAR's performance in these conditions, Fig. 4 shows the echo count from Velodyne' test run done in urban roads when the road was wet and salty. When compared to the reference run (Fig. 5) they appear similar: the echo count remains quite constant throughout the route. Some higher and lower points occur which are caused by other vehicles in front of the test car.

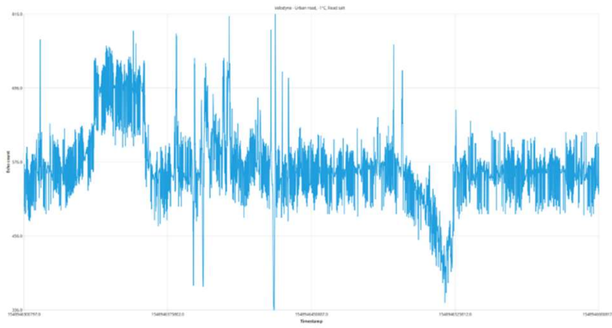

Fig. 4. Velodyne's echo count, salted water on the road surface at lower speeds.

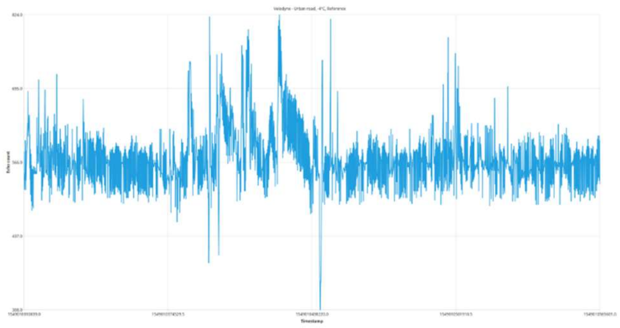

Fig. 5. Velodyne's echo count, reference run with dry road surface.

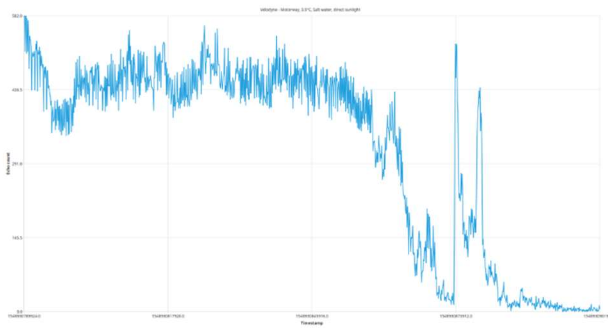

Fig. 6. Velodyne's echo count, salted water on the road surface at higher speeds.

However, Fig. 6 shows the echo counts from a test run performed on a wet motorway. At first, the Velodyne LiDAR produces high echo counts because of the mist cloud sprayed from the wet road surface. This appears as an impenetrable "wall" from LiDAR's point of view and its range measurement performance decreases significantly. After a while, there is a drop in the echo count because the spraying water dirties the sensor thus preventing it from measuring reliably.

Similar effect is observable in all the tested optical sensors: the spraying water cloud decreases the performance of LiDARs and stereo camera. In time, each of these fail to produce sensible data. On the contrary, the radar continues to perform well despite the harsh conditions.

## C. *Turbulent snow*

Turbulent snow tests were run on motorway on a frosty day with some light snowfall and turbulent snow caused by passing vehicles. These tests provided similar results as the salted water in that sense that the turbulent snow blocked the view of the optical sensors and distracted them. However, it did not prevent them from operating.

For Vislab's stereo camera and Cepton's and Ibeo's LiDARs (Fig. 7, Fig. 8 and Fig. 9), the graphs have similar shape. At first, there is lot of loose snow on the road surface and in the air. This causes high echo count values because - similarly to the spraying water cloud - the turbulent snow creates a distracting cloud in front of the sensor. In stereo camera's view, this cloud blurs the image thus increasing the blurriness index. Later, the road has cleared and the values are not as high as earlier.

On the other hand, this difference is barely noticeable when examining the echo count charts from Velodyne and Robosense (Fig. 10 and Fig. 11). However, when observing the point cloud data (Fig. 12), we see that the turbulent snow forms a cloud in front of the sensor but it does not prevent the sensor from monitoring the road ahead

Again, the radar is not affected by the turbulent snow or the snow fall.

## D. *Oncoming light*

Oncoming light tests were driven at low speeds in urban and semi urban roads. In general, the sensors were not affected by the bright sunlight but there were few exceptions.

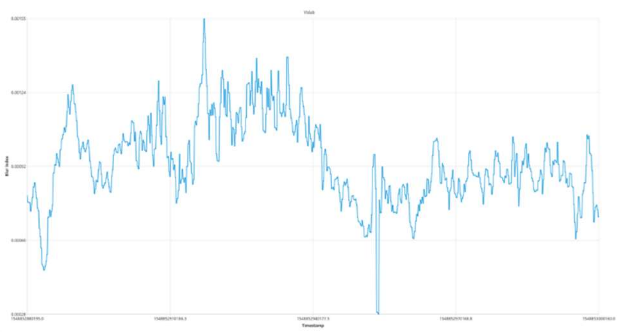

Fig. 7. Vislab's blurriness index, turbulent snow on motorway.

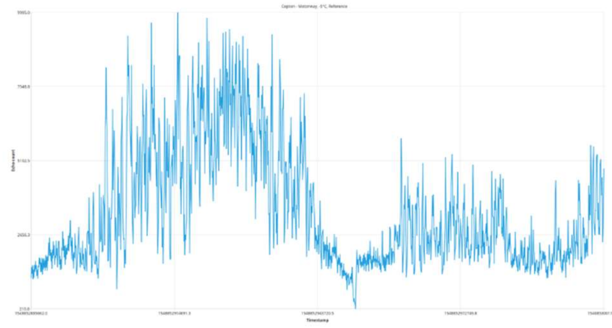

Fig. 8. Cepton's echo count, turbulent snow on motorway.

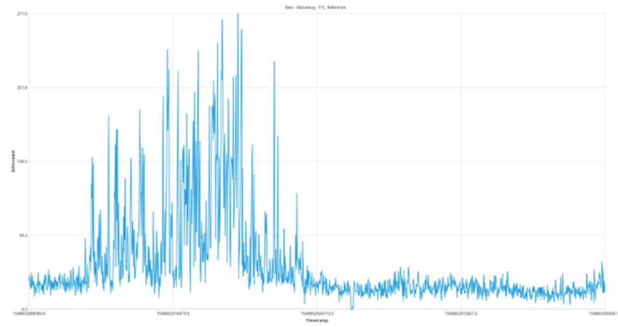

Fig. 9. Ibeo's echo count, turbulent snow on motorway.

Robosense's point clouds showed some flickering points in the sky in the sun's direction but its performance on ground level remains at the reference level.

Interestingly, Cepton did not tolerate the sunlight. Even the reflected sunlight from the snow banks caused trouble. In Fig. 13 we see how the echo count value is high because of the light hitting the sensor. Cepton interprets the sunlight as echoes but cannot define their distance thus marking them as zeroes. This increases the echo count but the point cloud itself does not contain any reasonable data.

The drop in the beginning of the graph is caused by a dark building. At this point, there is not much white snow reflecting the light nor is the sensor aimed directly at the sun. I.e., Cepton is not broken as it continues to measure and returns to its performance level once the bright light source has disappeared.

Stereo camera is also severely affected by the bright sunlight. The camera's images are overexposed which causes the details to disappear. In worst cases the whole view is blinded by the sunlight.

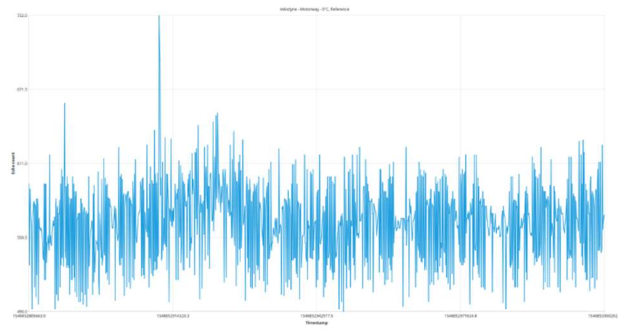

Fig. 10. Velodyne's echo count, turbulent snow on motorway.

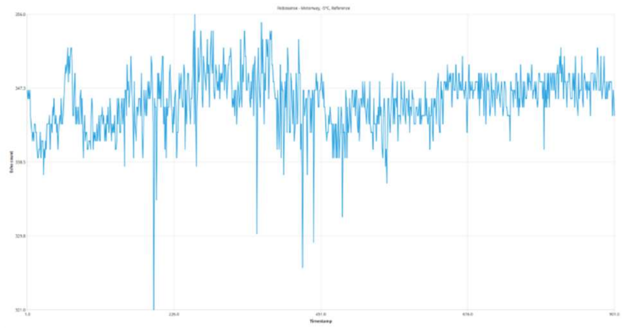

Fig. 11. Robosense's echo count, turbulent snow on motorway.

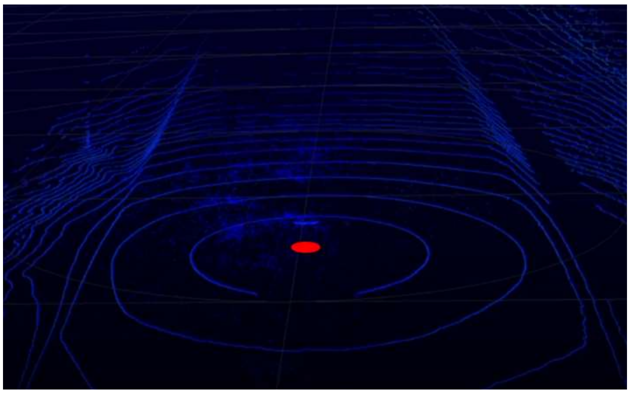

Fig. 12. Robosense's point cloud data, turbulent snow on motorway, sensor itself marked as a red dot.

## V. CONCLUSIONS

In this paper, we have presented results regarding performance of different LiDARs, stereo camera and radar in various test scenarios covering harsh, arctic weather and road conditions. We tested their behavior on wet and snowy road in subzero temperatures and additionally, with bright on-coming sunlight.

As is known and was expected, the LiDARs did not perform well in wet conditions. All of them lost their capability to measure reliably when the spraying water from the road surface reached their level. Since all the optical sensors were installed on the roof, this became an issue only at high speeds on motorway. Interestingly, the turbulent snow caused by passing vehicles had a similar effect but not as crucial as with water. Despite the distracting snow, the LiDARs were able to continue to measure and provide reasonable results. In general, the oncoming sunlight did not stop the LiDARs from working apart from Cepton which lost

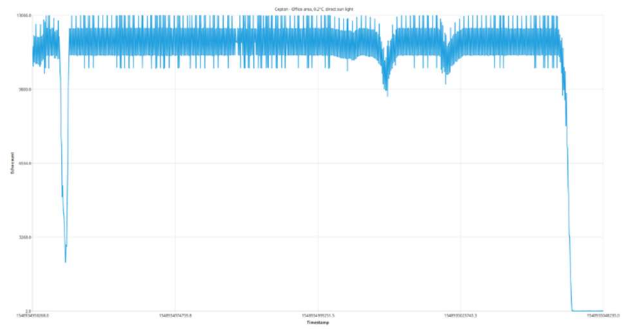

Fig. 13. Cepton's echo count, on-coming sunlight.

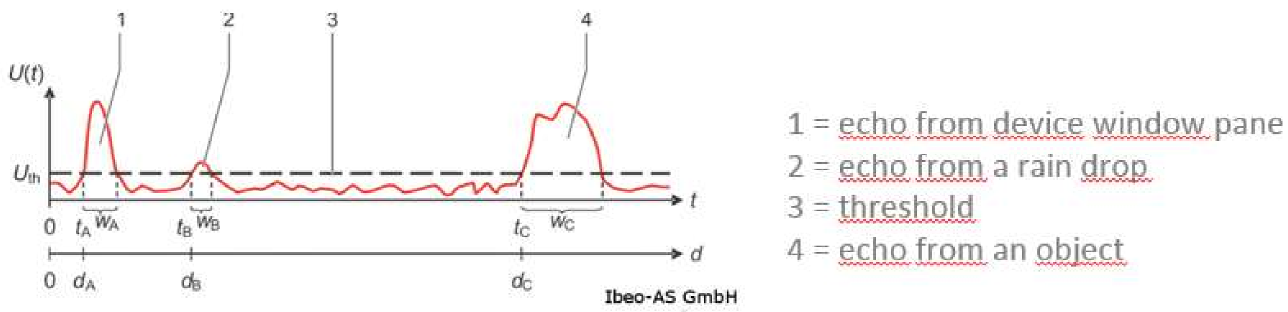


Fig. 14. LiDAR multi-echo behavior.

its ability to measure entirely. Stereo camera also had trouble with the bright sunlight as it causes overexposed images from which details are lost.

Cold temperatures decreased and even prevented few of the sensors from functioning as expected. Cepton and Robosense began to provide unusable point clouds the lower the temperature fell.

In conclusion, one sensor was not affected by the harsh weather conditions: the radar. It performed constantly well throughout the tests. Its drawback compared to LiDARs is that it can reliably detect only moving metallic objects, meaning that for example, pedestrians are not noticed. Radar's accuracy is also poorer than that of a LiDAR.

Harsh weather conditions are a permanent natural phenomenon which we cannot affect. Thus, if we want the automated vehicles to drive all kinds of weather, the sensors that the vehicles depend upon, must perform reliably in all conditions.

The following lists some countermeasures against the harsh winter environmental conditions we encountered. A dedicated cleaning system for the sensors is essential against the spraying salted water. It can be similar as used in the headlamp washer systems or even a small-sized wiper. In real road conditions the most dense sprayed salted water hovers over the road so higher location of the sensor is better.

Some software-based self-diagnostics can be applied. In case of a LiDAR Fig. 14 presents multiple echo reflections of a single transmitted laser pulse. Number 1 is echo from the window pane, which yield a high voltage over a short period of time. This first echo increases as the window pane gets dirtier. In camera-based systems image blurriness increases the dirtier the lens becomes.


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